# NAVAL HEALTH RESEARCH CENTER

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ANS | Autonomic Nervous System |
| BPM | Beats Per Minute |
| ECG | Electrocardiogram |
| FDA | United Stated Food and Drug Administration |
| FFT | Fast Fourier Transform |
| FRF | Fundamental Respiratory Frequency |
| HBI | Heart Beat Interval |
| HF | High Frequency |
| HR | Heart Rate |
| HRV | Heart Rate Variability |
| Hz | Hertz (cycles per second). |
| IHR | Instantaneous Heart Rate |
| LF | Low Frequency |
| LFa | Low Frequency area |
| LFa/HFa | Low Frequency area to High Frequency area Ratio |
| Mm of Hg | millimeters of Mercury |
| msec | Millisecond(s) |
| OR | Operating Room |
| PSNS | Parasympathetic Nervous System |
| RA | Respiratory Activity |
| Ratio | The division of the power in the Low-Frequency component by the power in the High-Frequency component |
| SNS | Sympathetic Nervous System |

## EXECUTIVE SUMMARY


### Problem

The physiologic status of patients undergoing surgical procedures requiring general anesthesia must be continuously monitored to ensure patient safety. New technologies capable of detecting even minute changes in physiologic status might be useful in providing feedback to operating room physicians as to any immediately resulting effects of their surgical interventions.

### Objective

The present study investigated autonomic nervous system (ANS) monitoring based on real-time Heart Rate Variability (rt-HRV) as a technique for monitoring the physiologic status of patients undergoing surgery.

### Approach

This study analyzed ANS monitoring and hemodynamic data collected on two populations of general anesthesia patients at William Beaumont Hospital in Royal Oak, MI. The patient populations were composed of individuals undergoing laparoscopic cholecystectomies and radical surgeries. The ANS monitoring data collected included: 1) low-frequency area (LFa, in beats per minute squared), 2) high-frequency area (HFa), and 3) the ratio of low- to high-frequency areas (LFa/HFa = Ratio). The hemodynamic data collected included: 1) heart rate, 2) mean arterial pressure, 3) arterial hemoglobin oxygen saturation measured by pulse oxymetry, and 4) inspired fraction of oxygen concentration.

### Results

The ANS monitoring parameter data were found to be more sensitive than the hemodynamic parameter data to changes in physiologic state resulting from anesthesia induction and sedation, intubation and extubation, incisions, surgical stimulation, and bleeding.

### Conclusion

This preliminary study provides evidence that ANS monitoring, using rt-HRV, may offer physicians additional information regarding the physiologic state of their general surgery patients beyond that obtained from traditional hemodynamic measures.

# AN EXAMINATION OF REAL-TIME HEART RATE VARIABILITY DURING LAPAROSCOPIC CHOLECYSTECTOMIES AND RADICAL SURGERIES

## INTRODUCTION

Monitoring of the autonomic nervous system (ANS) via real-time Heart Rate Variability (rt-HRV) analysis represents a unique and novel means of non-invasively assessing the physiologic status of humans.[1] The ability to monitor ANS activity is an important capability in that the ANS controls and coordinates the function of all of the visceral organs in order to promote homeostasis.[2] These visceral functions include: heart and lung action, blood pressure, reactions to stress and fatigue, reactions to loss of oxygen profusion, responses to blood loss, and reactions to medical treatments, levels of anesthesia, and chemical and biological insults. Heart rate variability analysis, thus, may functionally provide a means of monitoring the capacity of the ANS to carry out its life-sustaining functions. Indeed, there may be a predictive capability associated with rt-HRV in that once the human has received an insult, any post-insult deviations from the normal routine maintenance of homeostasis may be detectable via rt-HRV analysis. Further, detection of deviations from the normal functioning of the ANS may be possible earlier with rt-HRV than with other indicators, and thus may be an effective early-warning indicator of severe damage, distress, or disease.

ANS monitoring may be used as a continuous or periodic measure of health,[2] and might also have potential for medical applications during combat deployments. The technology's digital, real-time capabilities offer possible mechanisms for: 1) remote monitoring of deployed personnel; 2) continuous remote triage from forwards areas to field hospitals and hospital ships; and 3) monitoring of patients' physiologic states during surgeries, as well as during the pre-operative phase and during post-operative care and recuperation.

The present study examined the immediate impacts of various anesthesia and surgical interventions on two patient populations as measured by ANS monitoring and hemodynamic criteria. The patient populations included a group of laparoscopic cholecystectomy patients and a group of radical surgery patients (*e.g.*, radical prostatectomy patients, radical hysterectomy patients, and radical nephrectomy patients) at William Beaumont Hospital in Royal Oak, MI. The cholecystectomy patients underwent scheduled surgery that typically included very low levels of blood loss. The radical surgery patients underwent scheduled surgery that typically included higher levels of blood loss. The study is part of an effort to validate the application of

ANS monitoring in defining human physiologic status during the immediate intra-operative period.

## METHOD

### *Study Participants*

Fifty-seven patients were studied beginning shortly after their arrival in the operating room. Twenty-six of these were laparoscopic cholecystectomy patients (21 female, 5 male). The remaining 31 were radical surgery patients (10 female, 21 male). Of the 31 radical surgeries, 20 were radical prostatectomy patients, 2 were radical hysterectomy patients, 4 were exploratory laperotomy patients and the other 5 were surgeries not fitting into any of the above categories. The ages of both groups combined ranged from 19 to 66 years, with a mean of 44.88 ± 12.08 years. The ages of the laparoscopic cholecystectomy patients ranged from 19 to 57 years, with a mean of 37.12 ± 10.53 years. The ages of the radical surgery patients ranged from 28 to 66 years, with a mean of 51.39 ± 9.15 years.

Both ANS monitoring data and hemodynamic data were collected on the two groups of surgical patients. The ANS monitoring data collected were: 1) low-frequency area (LFa, in beats per minute squared ($BPM^2$)), 2) high-frequency area (HFa, in $BPM^2$), and 3) the ratio of low- to high-frequency areas (LFa/HFa = Ratio, unitless). The derivation of these three parameters are further discussed in the following section.

The hemodynamic data consisted of: 1) heart rate (HR, in BPM), 2) mean arterial pressure (MAP, in millimeters of Mercury (mm of Hg)), 3) arterial hemoglobin oxygen saturation by pulse oxymetry ($SapO_2$, in percent of 100(%)), and 4) inspired fraction of oxygen concentration ($FIO_2$, unitless).

### *Data Analysis*

Data were collected during the immediate intra-operative period. The anesthesia and surgical interventions included: 1) pre-operative motion artifact, 2) anesthesia induction, 3) intubation, 4) baseline, 5) incision, 6) bleeding, 7) surgical stimulation, 8) intra-operative motion artifact, 9) additional sedation, 10) intra-operative stable, 11) closing, 12) extubation, 13) immediate post-operative activities, and 14) return to consciousness. Heart rate variability and hemodynamic

measurements were recorded from immediately following entry into the operating room to immediately prior to the patient's departure from the operating room. The data were aggregated across each of the aforementioned operational phases, and means and standard errors were computed based on the number of separate observations from all of the patients.

### *Pre-operative Activities*

The procedures associated with the study were reviewed with each patient in the pre-operative holding area and verified by written informed consent. Administration of pre-operative medication included Midazolam (Benzodiazepine) and/or Fentanyl (a narcotic) based on individual patient need.

### *Intra-operative Activities*

Upon arrival of the patient in the operating room (OR), two ANS monitor leads were attached to the patient. General anesthesia was induced using standard anesthesia administration techniques in adherence to professional standards of care. Anesthesia methods included administration of an induction agent (Propofol or Thiopental), muscle relaxant (Succinylcholine, Rocuronium, and/or Vecuronium), and/or a narcotic (Fentanyl). Doses of all agents used were individualized for each patient by the anesthesia provider based on the patient's body weight, pre-existing drug sensitivities, and the surgical demands of the operation. After induction, anesthetic agents were periodically administered for the maintenance of anesthesia throughout the surgical procedure. Inhalation agents (Forane and Nitrous Oxide), narcotics, and muscle relaxants were used for maintenance. Patients were monitored using standard anesthesia protocols. ANS information, surgical interventions, and anesthetic manipulations were recorded throughout the surgical procedure until the conclusion of operation. Following emergence from the anesthetized state and the awakening of the patient, the ANS monitor was detached.

*ANS Monitoring*

Real-time heart rate variability is derived from an analysis of the EKG signal via examination of the beat-to-beat intervals. More specifically, rt-HRV is derived from spectral analysis of heart rate variability coupled with spectral analysis of the respiratory signal. The heart rate (HR) spectrum is computed from the instantaneous heart rate (IHR) signal and, simultaneously, a Fast Fourier Transform (FFT) is performed on the respiratory signal to develop the respiratory activity (RA) spectrum. The RA spectrum is a measure of the subtle changes in the respiratory cycles of a free breathing individual. Changes in the respiratory cycles have been found to be indicative of vagal or parasympathetic outflow and the influence of the parasympathetic branch of the ANS on the integrity of cardio-pulmonary homeostasis.[3,4] Even in regulated breathing, or mechanically ventilated patients, RA analysis provides information as to how the ANS is responding to and compensating for the respiratory activity that is present.

Figure 1 depicts the methodology for computing ANS monitoring parameters, which include the Low-Frequency area (LFa), the High-Frequency area (HFa), and the LFa/RFa ratio. From the RA spectrum the frequency of the peak mode is determined and defined as the "Fundamental Respiratory Frequency" (FRF). On the HR spectrum's frequency axis, a 0.08 Hz-wide window is centered on the FRF. This is the high-frequency (HF) region of the HR spectrum. The area under the HR spectral curve within the HF region is defined as the HFa, which is reflective of the relative power or tone of the parasympathetic nervous system (PSNS).[3,4] The region of the HR spectrum from 0.04 Hz to 0.12 Hz is defined throughout the HRV spectral analysis literature as the low-frequency (LF) region. The area under the HR spectral curve within the LF region is defined as the LFa. The LFa is a measure of the relative power or tone of the sympathetic nervous system (SNS) as it is mediated by the PSNS.

The Ratio (LFa/HFa) is a mathematical formula that, theoretically, divides the PSNS component from the combined SNS and PSNS components (as measured by the LFa). By simultaneously analyzing respiratory activity, the ambiguities associated with classical HRV are attenuated since a direct measure of the PSNS is available through the RA analysis.

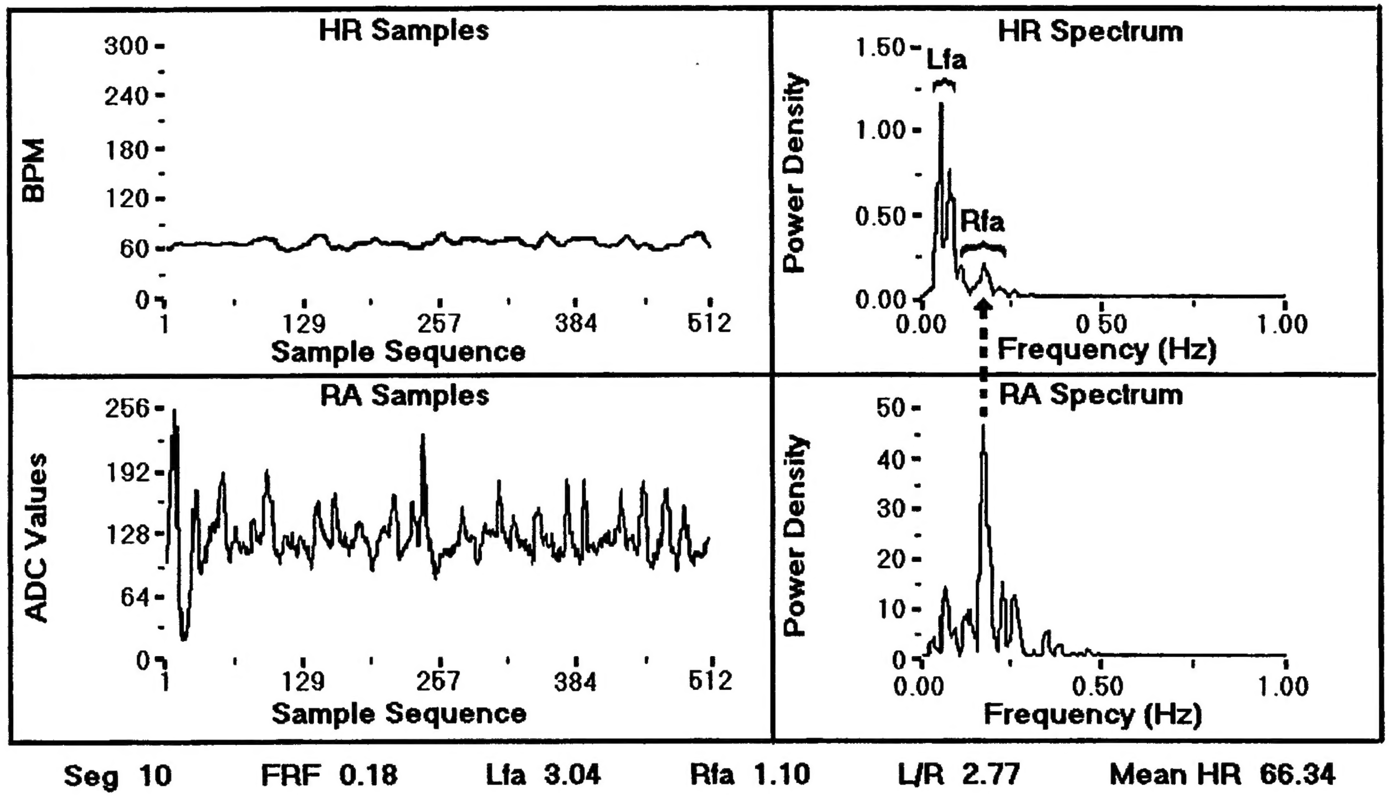


**Figure 1:** Methodology for computing ANS monitoring parameters: LFa, HFa, and Ratio. The left two panels show the 512 samples of the instantaneous heart rate (top) and respiratory activity (bottom) time-varying waveforms. The right two panels show the spectra for the two time-domain signals: heart rate (HR) spectrum (top) and respiratory activity (RA) spectrum (bottom). The peak mode of the RA spectrum, the fundamental respiratory frequency (FRF), provides the center frequency for the HFa analysis window. The LFa analysis window is placed based on "classical" HRV methods. The area under the HR spectral curve within these two windows is computed to provide the HF and LF ANS monitoring components, respectively. The Ratio is computed by dividing LF by HF. Every 32 seconds a new segment of data are analyzed, thereby updating the ANS monitoring parameters every 32 seconds.

## *The ANS-R1000*

The ANS data included in this report were recorded using an ANS-R1000 Autonomic Nervous System Monitoring System (Ansar, Inc., Philadelphia, PA). A brief description of the recordation process is as follows. The EKG and respiratory signals are collected from an apnea monitor (Model 9550 from Aequitron Medical, Inc., Minneapolis, Minnesota). The leads are placed in a Lead-II configuration using reusable black carbon fiber transduction patches. These patches permit the injection of a sub-threshold 30 mA, 60,000 Hz current and record respiratory activity via impedance plethysmography. Simultaneously, the EKG is recorded through the same patches, and while the EKG data are still an analog signal, the R-peaks are detected using proprietary hardware and software (Ansar, Inc., Philadelphia, PA). At this time, dual channel noise and artifacts are rejected, and skipped beats are interpolated.

The EKG and the respiratory signals are digitized at 512 Hz. From consecutive R-peaks, the beat-to-beat intervals are computed. The heart beat interval (HBI) series is made into a signal by connecting the HBIs with linear splines. The HBI signal is then low-pass filtered and converted into the instantaneous heart rate (IHR) signal. The IHR signal is sampled at 4 Hz, and the respiratory signal is down-sampled at 4 Hz; then 512 samples of each are separately sent to the Fast Fourier Transformation. The segments from the two separate signals that are sent to the FFT are matched so that they are from the same time period. Each series of 512 samples that are analyzed are considered a segment. The first segment consists of 512 new samples. Each successive segment consists of 128 new samples and the last 384 samples from the previous segment. Thus, in a "first in first out" format, each successive 32 second segment of data is analyzed. The result from each segment of data analysis is one sample each of the LFa, HFa, and LFa/HFa Ratio.

Certain segments are required by the FDA to be rejected. There are two rationales for rejecting a segment. The first is two-channel noise from the EKG. If the noise in the EKG and respiratory input channels to the ANS-R1000 are correlated, then the segment is rejected. The second is an FRF less than 0.161 Hz. If the FRF is less than 0.161 Hz, the HF and LF analysis windows overlap. Since both windows include PSNS information, and since the PSNS component in the LF window is unknown, an overlap would include double counting of an unknown quantity.

### *Hemodynamic Monitoring*

The hemodynamic monitoring data, specifically heart rate (HR), mean arterial pressure (MAP), arterial hemoglobin oxygen saturation by pulse oxymetry ($SapO_2$), and inspired fraction of oxygen concentration ($FIO_2$), were collected using a standard, surgical suite anesthesiology station. These data were recorded every 15 minutes throughout the period of ANS Monitoring on standard Beaumont Hospital Anesthesia Report forms.

### *ANS Monitoring Data*

The ANS-R1000 computes and stores a segment of ANS monitoring data every 32 seconds. The data segments that coincided with the various pre-operative, operative, and post-operative phases were aggregated and analyzed together. Means and standard errors were computed based upon the observations collected across all of the surgical patients, as well as separately for the laparoscopic cholecystectomy patients and for the radical surgery patient group.

## RESULTS

### *Overview*

The results of the initial data analysis of all of patients combined are displayed in Table 1. In this study, the pre-operative period includes four events: 1) pre-operative motion artifact, 2) anesthesia induction, 3) intubation, and 4) baseline. The intra-operative period includes eight events: 1) incision, 2) bleeding, 3) surgical stimulation, 4) intra-operative motion artifact, 5) additional sedation, 6) intra-operative stable, 7) closing, and 8) extubation. The post-operative period includes two events: 1) immediate post-operative activities, and 2) return to consciousness.

**TABLE 1:** ANS monitoring and hemodynamic data across all patients for each of the operation phases studied.

| | | LFa | HFa | Ratio | MAP | HR | SapO2 | FIO2 |
|---|---|---|---|---|---|---|---|---|
| Pre-op Motion Artifact | Mean | 29.66 | 45.20 | 0.89 | 73.09 | 86.68 | 99.36 | 0.60 |
| | st. error | 5.37 | 7.74 | 0.10 | 2.31 | 2.92 | 0.24 | 0.05 |
| Anesthetic Induction | Mean | 3.67 | 5.11 | 1.49 | 77.00 | 82.25 | 99.25 | 0.50 |
| | st. error | 2.93 | 4.16 | 0.63 | 8.22 | 5.94 | 0.48 | 0.00 |
| Intubation | Mean | 31.08 | 57.13 | 0.66 | 78.33 | 82.33 | 99.56 | 0.64 |
| | st. error | 7.24 | 17.93 | 0.08 | 4.40 | 4.01 | 0.24 | 0.08 |
| Pre-op Baseline | Mean | 1.63 | 1.23 | 4.38 | 69.85 | 81.93 | 99.54 | 0.48 |
| | st. error | 0.56 | 0.36 | 1.47 | 3.00 | 3.72 | 0.18 | 0.03 |
| Incision | Mean | 116.71 | 105.48 | 3.02 | 76.36 | 95.13 | 98.97 | 0.52 |
| | st. error | 16.30 | 12.87 | 1.01 | 1.53 | 2.34 | 0.15 | 0.02 |
| Bleeding | Mean | 171.99 | 161.51 | 2.36 | 75.92 | 94.13 | 99.08 | 0.54 |
| | st. error | 14.02 | 13.72 | 0.41 | 1.20 | 1.92 | 0.08 | 0.02 |
| Surgical Stimulation | Mean | 137.33 | 137.40 | 3.80 | 78.28 | 94.40 | 98.85 | 0.57 |
| | st. error | 13.89 | 13.52 | 2.15 | 1.17 | 1.63 | 0.17 | 0.02 |
| Intra-op Motion Artifact | Mean | 63.92 | 81.51 | 1.49 | 80.33 | 88 | 98.64 | 0.55 |
| | st. error | 27.07 | 27.50 | 0.58 | 2.82 | 5.2 | 0.45 | 0.07 |
| Added Sedation | Mean | 0.33 | 0.31 | 6.69 | 79.81 | 76.43 | 98.91 | 0.53 |
| | st. error | 0.09 | 0.07 | 4.44 | 1.82 | 2.04 | 0.16 | 0.03 |
| Stable | Mean | 0.38 | 0.32 | 2.29 | 76.50 | 81.42 | 99.38 | 0.56 |
| | st. error | 0.09 | 0.11 | 0.39 | 2.04 | 2.6 | 0.22 | 0.05 |
| Closing | Mean | 63.37 | 87.99 | 1.71 | 82.26 | 87.85 | 99.45 | 0.65 |
| | st. error | 18.22 | 27.92 | 0.44 | 3.67 | 4.18 | 0.28 | 0.09 |
| Extubation | Mean | 44.84 | 48.22 | 1.66 | 80.35 | 88.42 | 99.81 | -- |
| | st. error | 9.79 | 10.52 | 0.36 | 3.05 | 2.64 | 0.14 | -- |
| Post-op | Mean | 0.62 | 0.82 | 2.52 | 89.44 | 86.77 | 98.13 | 0.34 |
| | st. error | 0.15 | 0.25 | 0.47 | 3.17 | 2.57 | 0.39 | 0.03 |
| Post-op Conscious | Mean | 113.30 | 103.3 | 1.87 | 86.17 | 88.38 | 99.00 | 0.28 |
| | st. error | 40.02 | 23.77 | 0.53 | 7.35 | 3.72 | 0.68 | 0.02 |

*Pre-operative period*

As can be seen in Table 1, within the pre-operative period there was considerable variability in mean LFa and Hfa associated with pre-operative motion by the patient and intubation, while MAP, HR, $SapO_2$, and $FIO_2$ remained relatively constant. The mean LFa and HFa upon anesthesia induction were 3.67 ± 2.93 and 5.11 ± 4.26, respectively; at the pre-operative baseline these values were 1.63 ± 0.56 and 1.23 ± 0.36, respectively. The LFa/HFa Ratios for the induction and pre-operative baseline were 1.49 ± 0.63 and 4.38 ± 1.47, respectively. The LFa and HFa values at anesthesia induction showed large standard errors, probably due to the differing rates of anesthesia absorption across the patient cohort. The low mean values for the LFa and HFa during the pre-operative baseline showed relatively small standard deviations, and are reflective of the general stability of these components during the anesthetized state. The LFa/HFa Ratio at anesthesia induction is relatively low and can be seen to increase at the pre-operative baseline once the patients is more stable. This change is likely due to the differential effects of the anesthesia on the individual branches of the ANS.

The mean LFa, HFa, and Ratio values on intubation were 31.08 ± 7.24, 57.13 ± 17.93, and to 0.66 ± 0.08, respectively (see Table 1). During this time the MAP, HR, and $SapO_2$ were essentially unchanged from their normal range. The rises in LFa and HFa are reflective of the stresses from the intubation being perceived at the brainstem level, even though cortical perception is blocked by the anesthesia. The stresses, however, are not sympathetic (since the LFa/HFa Ratio is low), but rather are parasympathetic, as is indicated by the high HFa. Thus, the intubation stresses appear to be the result of vagal stimulation in the lower airways.

***Intra-operative period***

The LFa and HFa values rose abruptly and strikingly at the time of the incision to mean values of 116.71 ± 16.33 and 105.48 ± 12.87, respectively (see Table 1). The LFa/HFa Ratio was relatively unchanged from the pre-operative baseline. As with the intubation, the rise in the Ratio at the time of the incision appears to be the result of parasympathetic stimulation, possibly due to vagal stimulation through surgical manipulation of the peritoneum and viscera. The stability of the Ratio indicates stability in the SNS, possibly as a result of the anesthesia.

With the onset of bleeding, there were further increases in LFa and HFa to the highest levels observed intra-operatively: 171.99 ± 14.02 and 161.51 ± 13.72. Again the LFa/HFa ratio was relatively unchanged. The stimulation produced during surgical manipulation yielded high LFa and HFa values (137.33 ± 13.89 and 137.40 ± 13.52) with relatively unchanged Ratios. These values point to an elevated PSNS tone. This is not unexpected because 1) bleeding causes a reduced venous return to the heart causing an increased parasympathetic response, and 2) the viscera is heavily innervated by the vagus nerve, thus strong parasympathetic responses are reasonable upon surgical manipulation of the viscera.

Although all patients were anesthetized, there was occasional movement by the patient. The resulting parasympathetic and sympathetic changes were less pronounced than those resulting from surgical manipulation (see Table 1: Intra-op Motion Artifact, Surgical Stimulation). When additional doses of sedation were given, there were pronounced reductions in LFa and HFa values. The Ratios increased appreciably during 'added sedation' (6.69 ± 4.44) but returned to their relatively unchanged values when the ANS stabilized (2.29 ± 0.39). There were increases in the LFa, HFa and Ratio values during closing of the operative wound; this in part may be attributable to the common practice of lightening the anesthetic dose 30 to 40 minutes prior to closing so that the patient will wake more easily post-operatively.

***Post-operative period***

At the beginning of the post-operative period, the patients were extubated. There were increases in LFa and HFa upon extubation, and after waking up and regaining a level of consciousness (see Table 1). As with intubation, the increases in LFa and HFa during extubation are likely reflective of PSNS stimulation through the vagus nerve. That the LFa/HFa Ratio is lower during extubation than during the operation is probably a function of the remaining anesthesia, compounded by the opposing effects the PSNS has on the SNS.

In the immediate post-operative period the LFa and HFa values (from Table 1: 0.62 ± 0.15 and 0.82 ± 0.25, respectively) are higher by factors of almost two and three respectively, than during the intra-operative stable period. This is indicatative of the patients' return to consciousness. At this time, the LFa/HFa Ratio (2.52 ± 0.47) has returned to normal, but is lower than the pre-operative (post-induction) values. This decrease is indicative of stability and possibly reflects the dissipation of pre-operative anxiety. As the patients regained full consciousness, the LFa and HFa values increased (113.30 ± 40.02

and 103.30 ± 23.77, respectively), presumably in part due to PSNS-mediated healing effects. The Ratio (1.87 ± 0.53) remained normal; a further indication of stability.

*Laparoscopic Cholecystectomies v. Radical Surgeries*

As seen in Figure 2 and Tables 3 and 4, the data indicate increased LFa values in the radical surgery group during much the surgical period, although these values were obtunded by additional sedation and during stable periods. The LFa increases for the radical surgery patients were greater than the laparoscopic cholecystectomy group during the incision, surgical exploration, and periods of active bleeding. Similarly, the HFa values were often higher in the major surgery group.

There was a tendency for the radical surgery patients to have higher LFa/HFa Ratios throughout most of the intra-operative period than was observed with the cholecystectomy patients. This is indicative of an elevated sympathetic response of the radical surgery patients. These data are consistent with the concept that major surgery itself generates slightly more sympathetic and parasympathetic activity than does the less traumatic laparoscopic cholecystectomies. However, sudden intraoperative blood loss in both groups led to comparable degrees of increased sympathetic and parasympathetic activity. The fact that the LFa/HFa Ratio is consistently higher for the higher blood loss operations (radical surgeries) is reflective of the sympathetic stress induced by hypovolemia.

As seen in Figure 3, the hemodynamic data did not show substantial differences between the low blood loss patients (cholecystectomies) and the high blood loss patients (radical surgeries), except for the heart rate measure during the 'Added Sedation" phase of the operation. Thus, non-invasive ANS monitoring seems to be more sensitive to blood loss than does non-invasive hemodynamic monitoring.

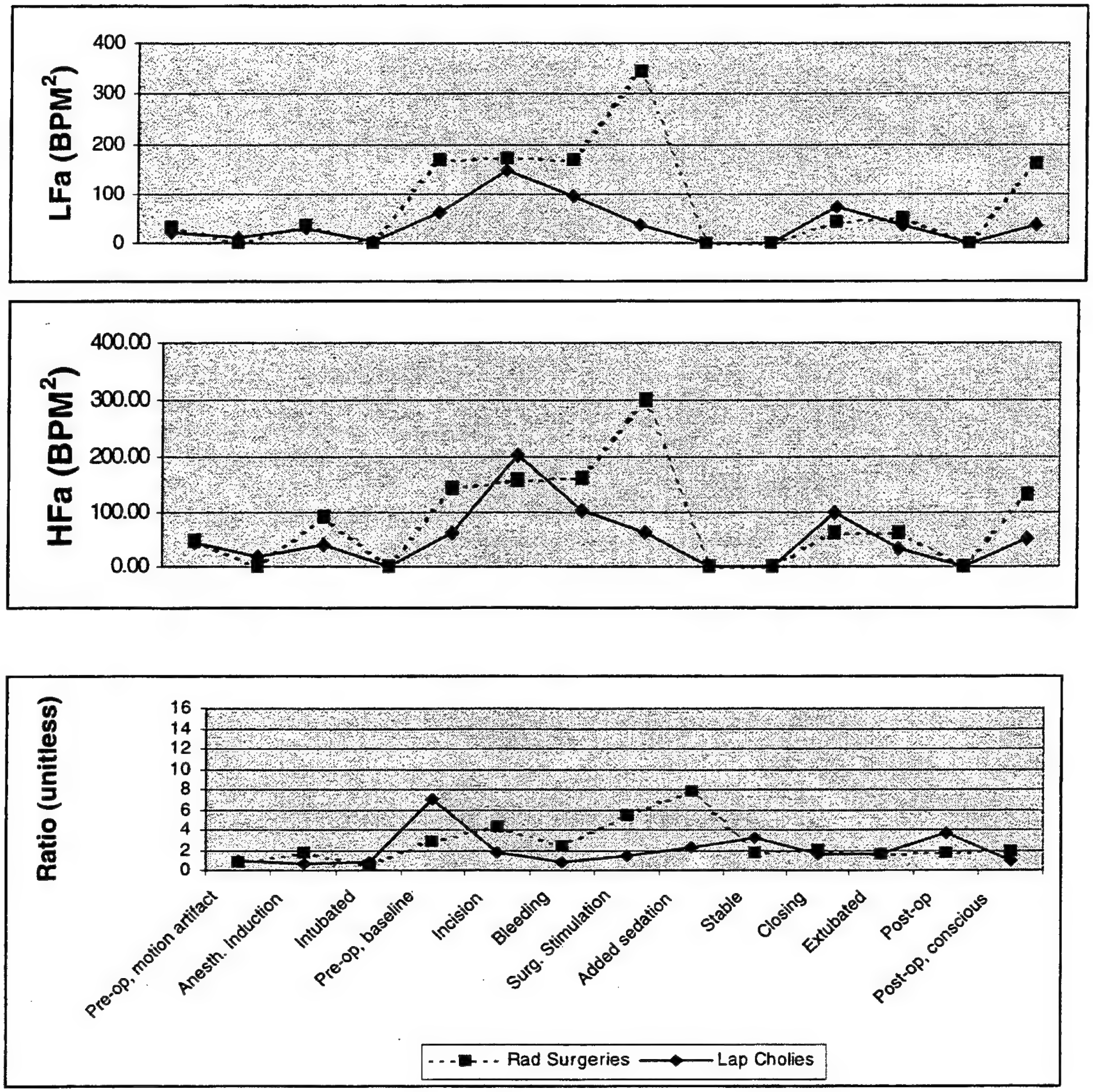


**Figure 2:** ANS monitoring data during operational phases for 26 low-blood loss laparoscopic cholecystectomy patients (solid line) and 31 high-blood loss radical surgery patients (broken line).

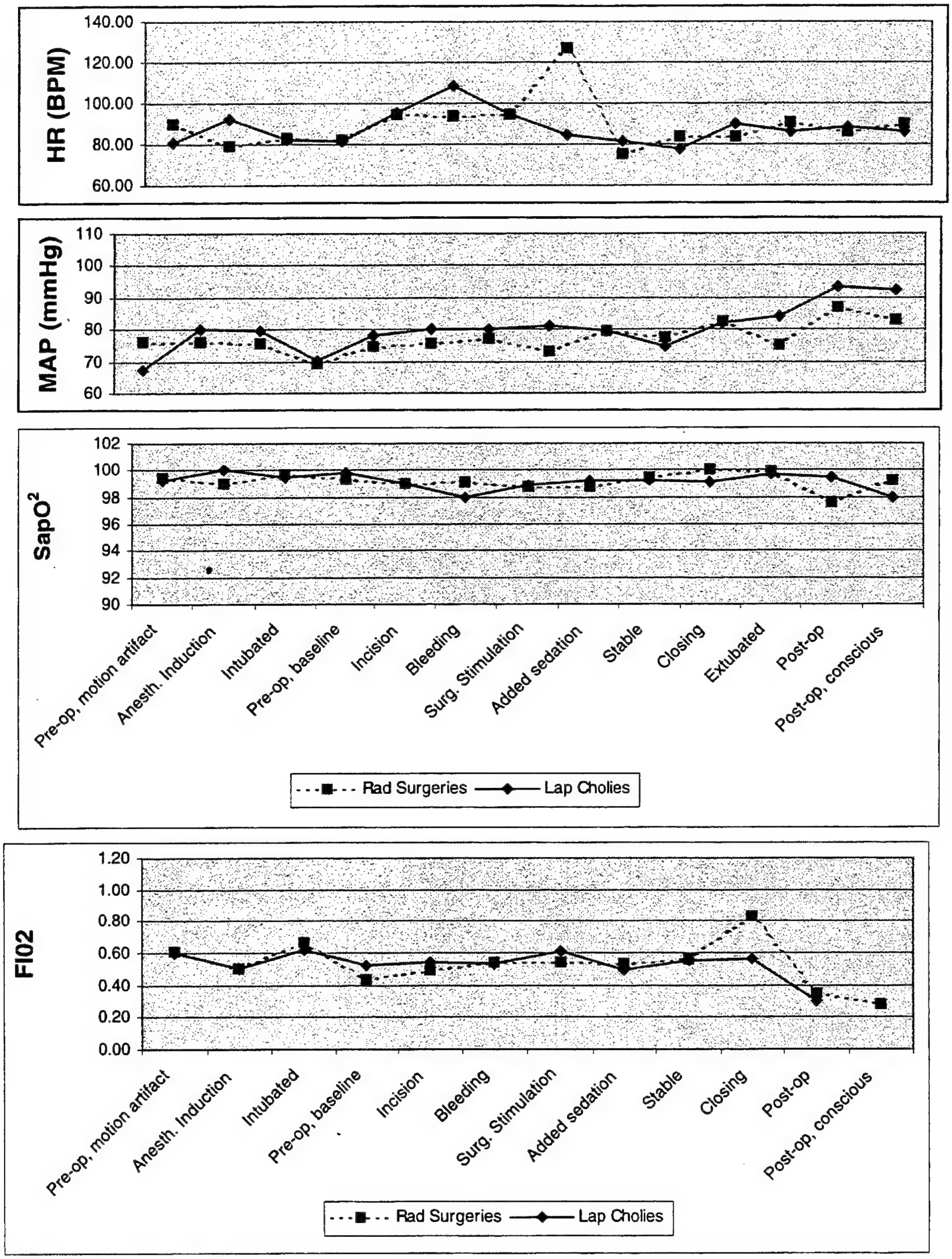


**Figure 3**. Hemodynamic data during operational phases for 26 low-blood loss laparoscopic cholecystectomy patients (solid line) and 31 high-blood loss radical surgery patients (broken line).

**TABLE 2:** ANS monitoring and hemodynamic data for the 26 laparoscopic cholecystectomy patients.

| | | LFa | HFa | Ratio | MAP | HR | SapO2 | FIO2 |
|---|---|---|---|---|---|---|---|---|
| Pre-op Motion Artifact | Mean | 22.24 | 42.90 | 1.00 | 67.50 | 80.88 | 99.25 | 0.60 |
| | st. error | 5.97 | 16.41 | 0.14 | 2.70 | 2.66 | 0.25 | 0.07 |
| Intubation | Mean | 28.30 | 38.96 | 0.73 | 79.67 | 82.00 | 99.50 | 0.62 |
| | st. error | 10.39 | 14.33 | 0.09 | 6.15 | 5.89 | 0.34 | 0.10 |
| Pre-op Baseline | Mean | 3.03 | 1.45 | 7.08 | 70.40 | 81.40 | 99.80 | 0.52 |
| | st. error | 1.66 | 0.57 | 2.56 | 4.20 | 5.85 | 0.20 | 0.03 |
| Incision | Mean | 62.88 | 64.48 | 1.70 | 78.10 | 95.32 | 98.97 | 0.55 |
| | st. error | 15.86 | 12.83 | 0.40 | 2.23 | 3.18 | 0.22 | 0.03 |
| Bleeding | Mean | 148.44 | 203.50 | 0.78 | 80.00 | 108.50 | 98.00 | 0.53 |
| | st. error | 90.05 | 93.01 | 0.21 | 15.00 | 12.50 | 1.00 | 0.07 |
| Surgical Stimulation | Mean | 94.38 | 103.24 | 1.51 | 80.00 | 94.58 | 98.92 | 0.61 |
| | st. error | 15.79 | 13.39 | 0.28 | 1.65 | 2.71 | 0.31 | 0.04 |
| Intra-op Motion Artifact | Mean | 38.44 | 61.52 | 1.34 | 81.00 | 84.45 | 98.50 | 0.57 |
| | st. error | 10.03 | 20.70 | 0.62 | 3.01 | 4.17 | 0.48 | 0.08 |
| Added Sedation | Mean | 0.33 | 0.20 | 2.22 | 79.78 | 81.22 | 99.22 | 0.50 |
| | st. error | 0.19 | 0.11 | 0.58 | 5.08 | 4.85 | 0.32 | 0.02 |
| Stable | Mean | 0.26 | 0.15 | 3.14 | 74.78 | 77.67 | 99.22 | 0.55 |
| | st. error | 0.09 | 0.05 | 0.83 | 2.34 | 3.14 | 0.36 | 0.07 |
| Closing | Mean | 72.52 | 99.52 | 1.54 | 82.00 | 89.67 | 99.14 | 0.56 |
| | st. error | 24.77 | 37.99 | 0.48 | 3.47 | 4.79 | 0.40 | 0.09 |
| Extubation | Mean | 37.94 | 33.47 | 1.68 | 84.10 | 85.77 | 99.75 | -- |
| | st. error | 12.12 | 10.51 | 0.53 | 2.95 | 4.02 | 0.25 | -- |
| Post-op | Mean | 0.60 | 0.84 | 3.71 | 93.09 | 88.12 | 99.43 | 0.30 |
| | st. error | 0.19 | 0.32 | 0.99 | 3.89 | 4.98 | 0.43 | 0.00 |
| Post-op Conscious | Mean | 38.48 | 52.78 | 0.94 | 92.50 | 86.00 | 98.00 | -- |
| | st. error | 23.02 | 20.69 | 0.23 | 8.50 | 6.98 | -- | -- |

**TABLE 3:** ANS monitoring and hemodynamic data for the 31 radical surgery patients.

| | | LFa | HFa | Ratio | MAP | HR | SapO2 | FIO2 |
|---|---|---|---|---|---|---|---|---|
| Pre-op Motion Artifact | Mean | 33.90 | 46.51 | 0.83 | 76.29 | 90.00 | 99.43 | 0.61 |
| | st. error | 7.65 | 8.31 | 0.14 | 3.03 | 4.14 | 0.17 | 0.07 |
| Anesthetic Induction | Mean | 0.77 | 1.00 | 1.77 | 76.00 | 79.00 | 99.00 | 0.50 |
| | st. error | 0.57 | 0.90 | 0.80 | 11.53 | 7.02 | 0.58 | 0.00 |
| Intubation | Mean | 36.63 | 91.67 | 0.53 | 75.67 | 83.00 | 99.67 | 0.67 |
| | st. error | 8.09 | 44.02 | 0.14 | 6.17 | 4.36 | 0.33 | 0.17 |
| Pre-op Baseline | Mean | 0.86 | 1.11 | 2.88 | 69.50 | 82.22 | 99.38 | 0.44 |
| | st. error | 0.33 | 0.49 | 1.70 | 4.32 | 5.04 | 0.26 | 0.04 |
| Incision | Mean | 167.27 | 143.99 | 4.26 | 74.43 | 94.94 | 98.97 | 0.49 |
| | st. error | 25.13 | 19.80 | 1.91 | 2.09 | 3.46 | 0.22 | 0.01 |
| Bleeding | Mean | 171.54 | 160.53 | 2.40 | 75.82 | 93.79 | 99.11 | 0.54 |
| | st. error | 14.26 | 13.94 | 0.42 | 1.20 | 1.94 | 0.08 | 0.02 |
| Surgical Stimulation | Mean | 168.25 | 162.00 | 5.45 | 77.04 | 94.26 | 98.80 | 0.54 |
| | st. error | 20.02 | 20.58 | 3.69 | 1.61 | 2.03 | 0.18 | 0.03 |
| Added Sedation | Mean | 0.34 | 0.34 | 7.84 | 79.82 | 75.20 | 98.82 | 0.53 |
| | st. error | 0.10 | 0.09 | 5.58 | 1.91 | 2.23 | 0.18 | 0.03 |
| Stable | Mean | 0.44 | 0.42 | 1.77 | 77.53 | 83.67 | 99.47 | 0.56 |
| | st. error | 0.13 | 0.17 | 0.33 | 2.97 | 3.67 | 0.29 | 0.07 |
| Closing | Mean | 42.79 | 62.05 | 2.09 | 82.75 | 83.75 | 100.00 | 0.83 |
| | st. error | 20.69 | 33.91 | 1.04 | 10.16 | 9.04 | 0.00 | 0.17 |
| Extubation | Mean | 51.75 | 62.96 | 1.64 | 75.00 | 91.08 | 99.88 | |
| | st. error | 15.63 | 17.74 | 0.51 | 5.79 | 3.41 | 0.13 | |
| Post-op | Mean | 0.64 | 0.81 | 1.75 | 86.94 | 85.88 | 97.56 | 0.35 |
| | st. error | 0.22 | 0.35 | 0.37 | 4.63 | 2.81 | 0.47 | 0.03 |
| Post-op Conscious | Mean | 160.07 | 134.87 | 1.96 | 83.00 | 89.88 | 99.20 | 0.28 |
| | st. error | 58.83 | 32.42 | 0.85 | 10.62 | 4.52 | 0.80 | 0.02 |

## SUMMARY

The purpose of this investigation was to apply a heart rate variability measuring device (the ANS-R1000) to anesthetized patients undergoing surgery to determine the device's sensitivity to the status of the autonomic nervous system and its individual branches, the SNS and the PSNS. Thus, the physiologic status of elective surgery patients at Beaumont Hospital was studied during their immediate peri-operative phases. The data showed logical changes in the ANS monitoring parameters with the various surgical periods the patients experienced (*e.g.*, anesthesia induction, intubation, incision, surgical manipulation, closing, and extubation). The ANS monitoring indicated differences in the LFa/HFa ratios between the higher-blood loss radical surgery patients and the lower-blood loss laparoscopic cholecystectomy patients. Such a difference between the two surgery cohorts was not readily detectable with any of the non-invasive hemodynamic measures included in the study.

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**14. ABSTRACT (maximum 200 words)**

This study examined the impact of a variety of anesthesia and surgical intervention on the patient as measured by ANS monitoring and hemodynamic techniques. Data were collected on two populations of general anesthesia patients at William Beaumont Hospital in Royal Oak, MI. The two populations included: laparoscopic cholecystectomy patients and radical surgery patients (*e.g.*, radical prostatectomy patients, radical hysterectomy patients, and radical nephrectomy patients). The ANS monitoring data collected included: 1) low-frequency area (LFa, in beats per minute squared ($BPM^2$)), 2) high-frequency area (HFa, in $BPM^2$), and 3) the ratio of low- to high-frequency areas (LFa/HFa = Ratio, unitless). The hemodynamic data collected included: 1) heart rate (HR, in BPM), 2) mean arterial pressure (MAP, in millimeters of Mercury (mm of Hg)), 3) arterial hemoglobin oxygen saturation by pulse oxymetry ($SapO_2$, in percent of 100(%)), and 4) inspired fraction of oxygen concentration ($FIO_2$, unitless). One of the ANS monitoring parameters (the LFa/HFa Ratio) showed a somewhat greater sensitivity than the hemodynamic measures to changes in physiologic state, including anesthesia and sedation, intubation and extubation, incisions, surgical stimulation, bleeding, and post-operative recovery.

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